Jet Propulsion Laboratory
California Institute of Technology

Observations of ground-reflected Global Navigation Satellite System signals from space

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Outline

- Forward vs. backscatter
- Spaceborne GNSS-Reflectometry data
- Sensitivity to near-surface soil moisture
- Sensitivity to landscape freeze/thaw state
- Future work

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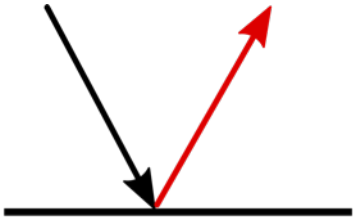
- **Forward vs. backscatter**
- **Spaceborne GNSS-Reflectometry data**
- **Sensitivity to near-surface soil moisture**
- **Sensitivity to landscape freeze/thaw state**
- **Future work**

Monostatic Radar

Measures backscatter

Bistatic Radar

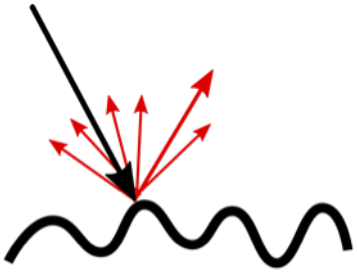
Measures forward scatter



Smooth surface

Low backscatter

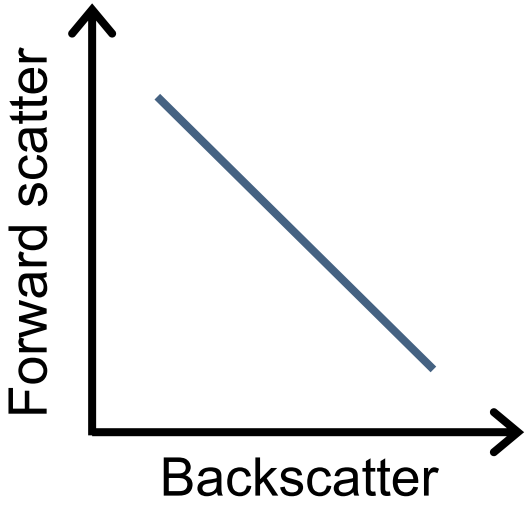
High forward scatter



Rough surface

High backscatter

Low forward scatter

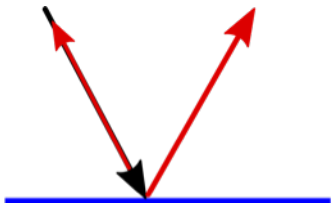


Monostatic Radar

Measures backscatter

Bistatic Radar

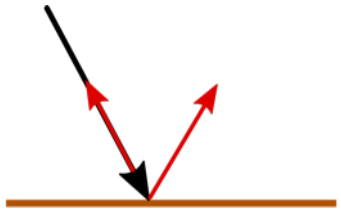
Measures forward scatter



Wet surface

High backscatter

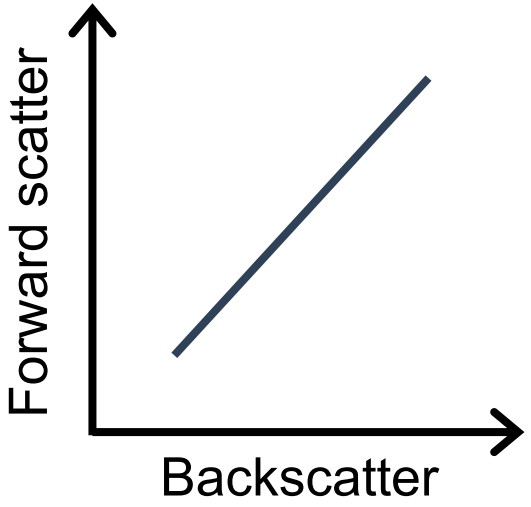
High forward scatter



Dry surface

Low backscatter

Low forward scatter

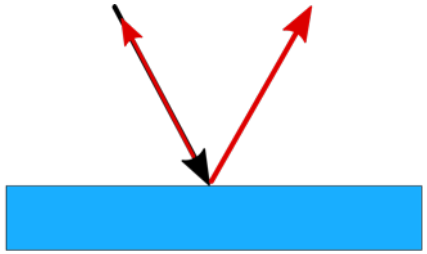


Monostatic Radar

Measures backscatter

Bistatic Radar

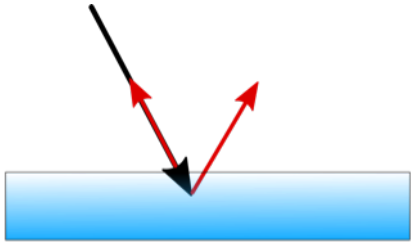
Measures forward scatter



Thawed surface

High backscatter

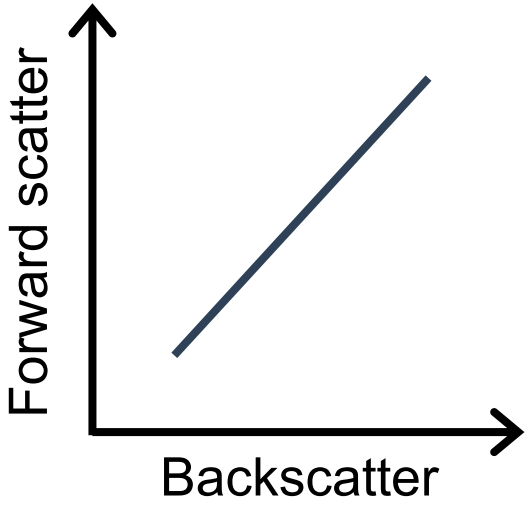
High forward scatter

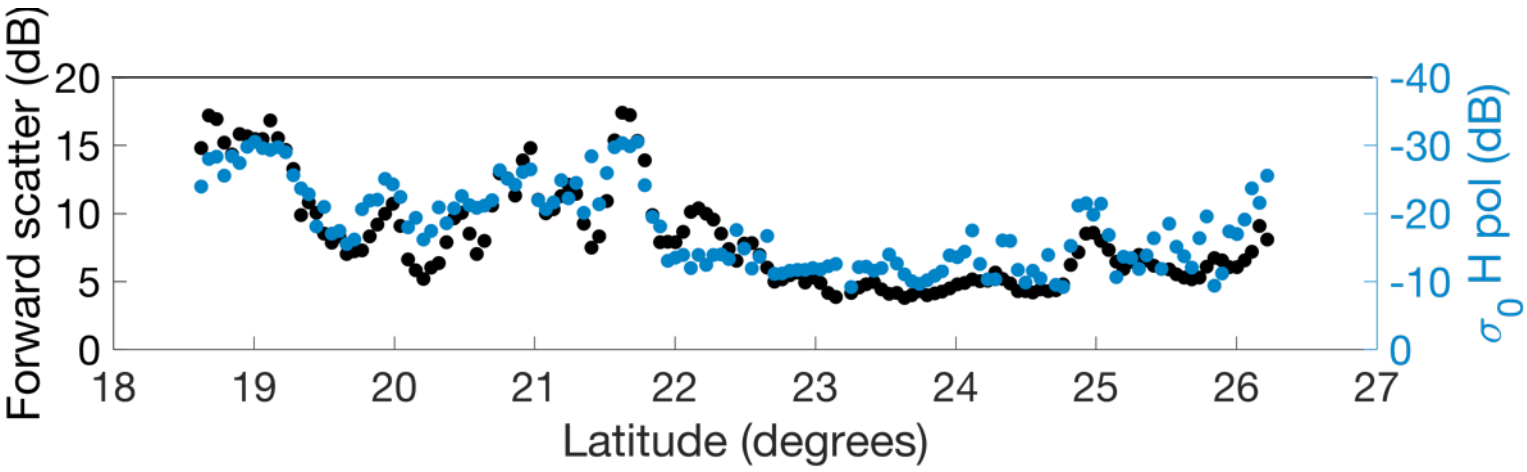


Frozen surface

Low backscatter

Low forward scatter




Forward scatter (dB)
20
15
10
5
0
-40
-30
-20
-10
0
σ_0 H pol (dB)
18
19
20
21
22
23
24
25
26
27
Latitude (degrees)

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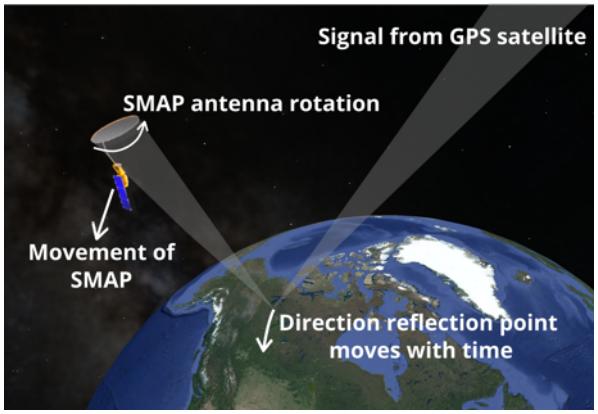
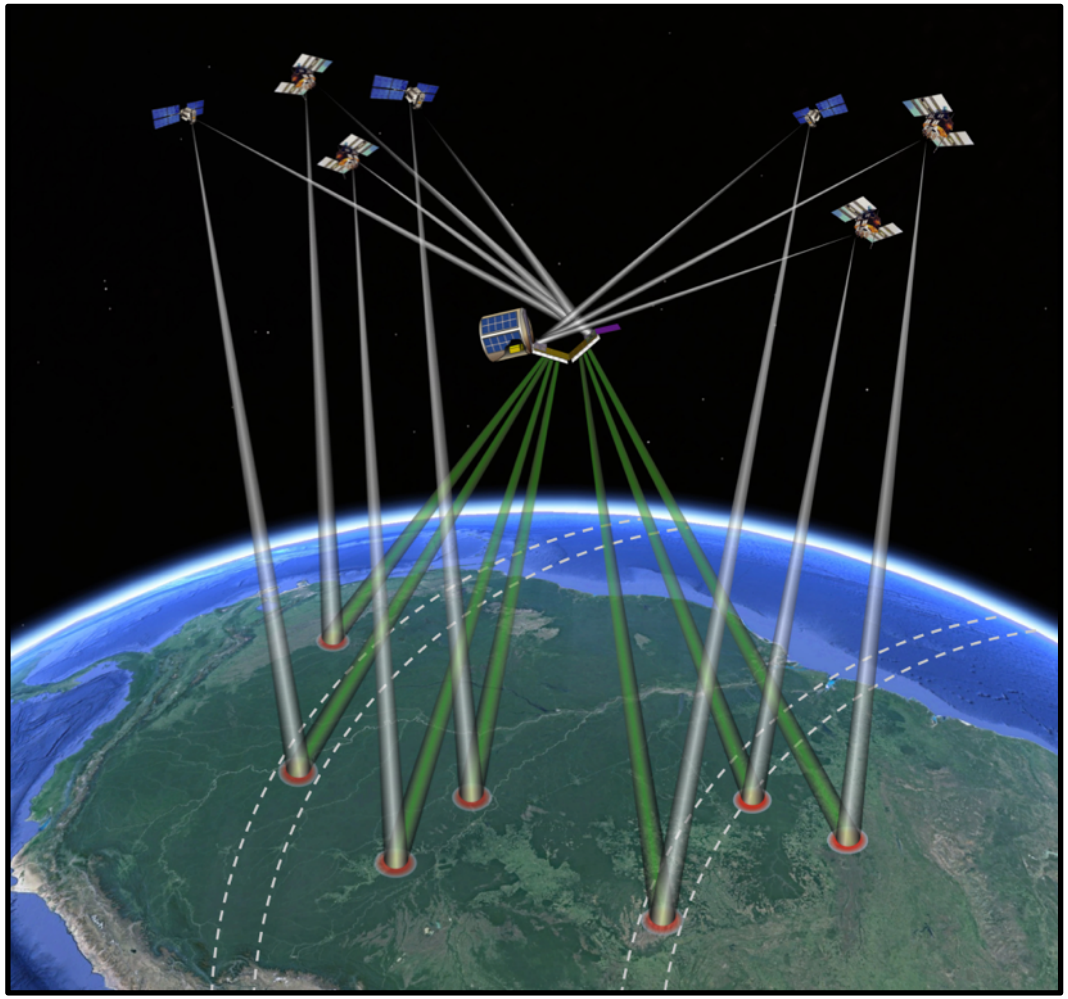
Sources of spaceborne reflections

1. **Soil Moisture Active Passive (SMAP) radar receiver:**
- H and V ~36 dB
- Data since Aug 2015
- Polar orbiting

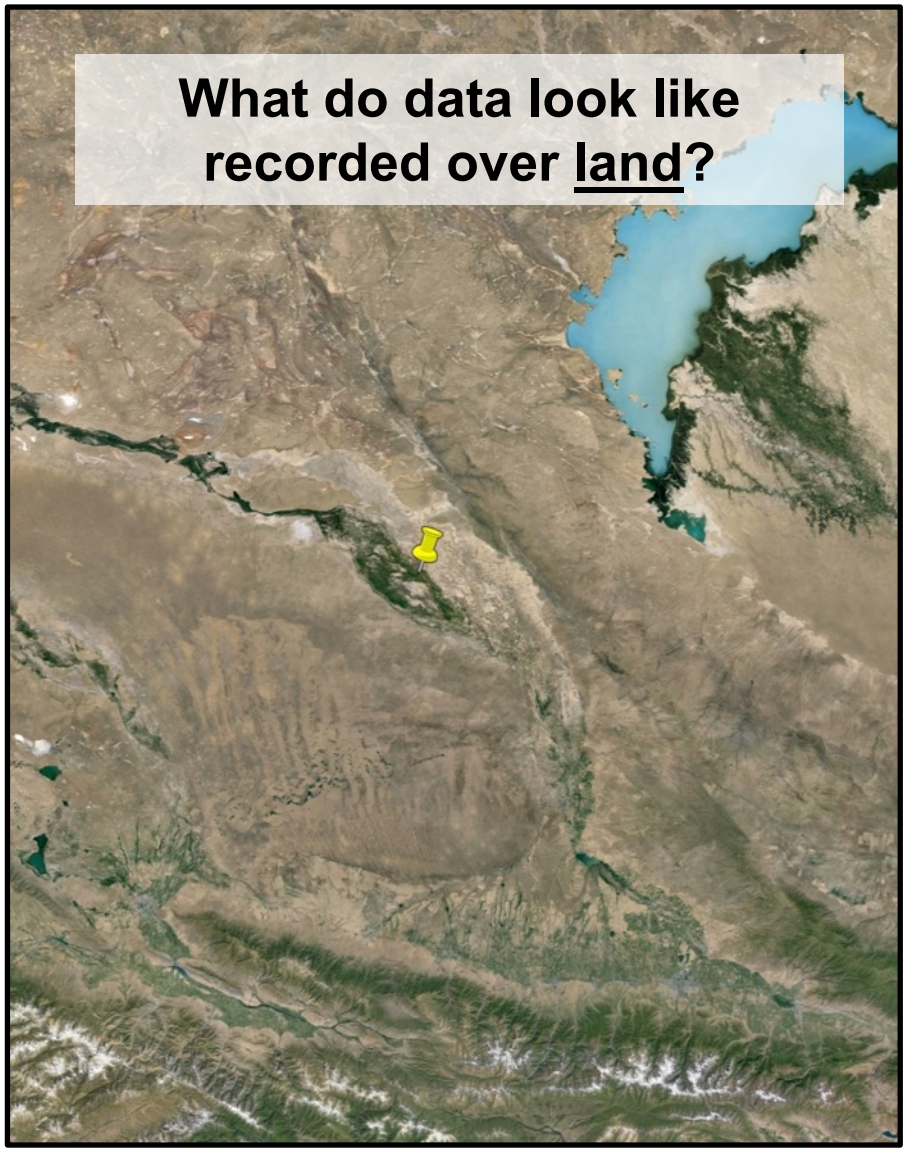
2. **TechDemoSat-1 (TDS-1):**
- LHCP antenna ~13 dB
- Data every 8 days since July 2014
- Polar orbiting

3. **Cyclone GNSS (CyGNSS):**
- LHCP antenna ~13 dB
- Launched Dec 2016, no data yet
- Orbits the tropics

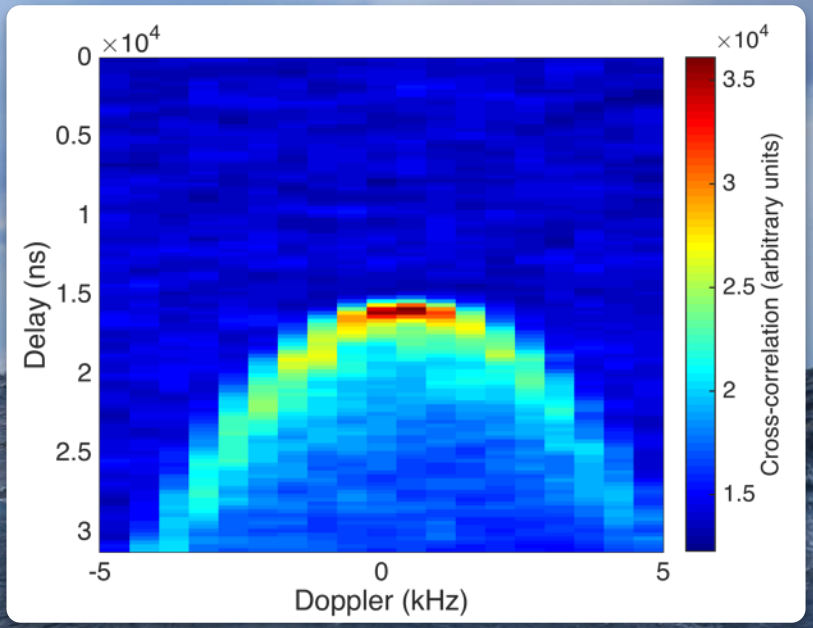





What do data look like recorded over the ocean?

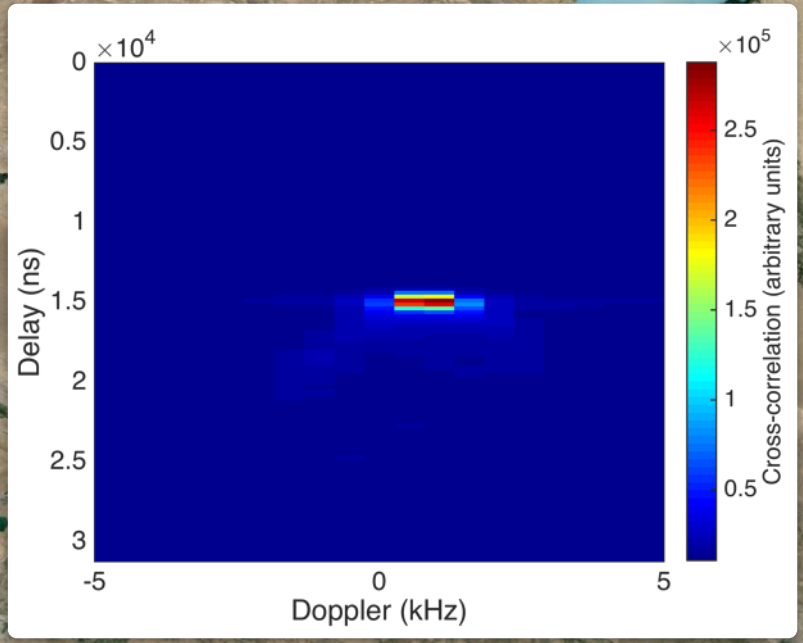

What do data look like recorded over land?

What do data look like recorded over the ocean?



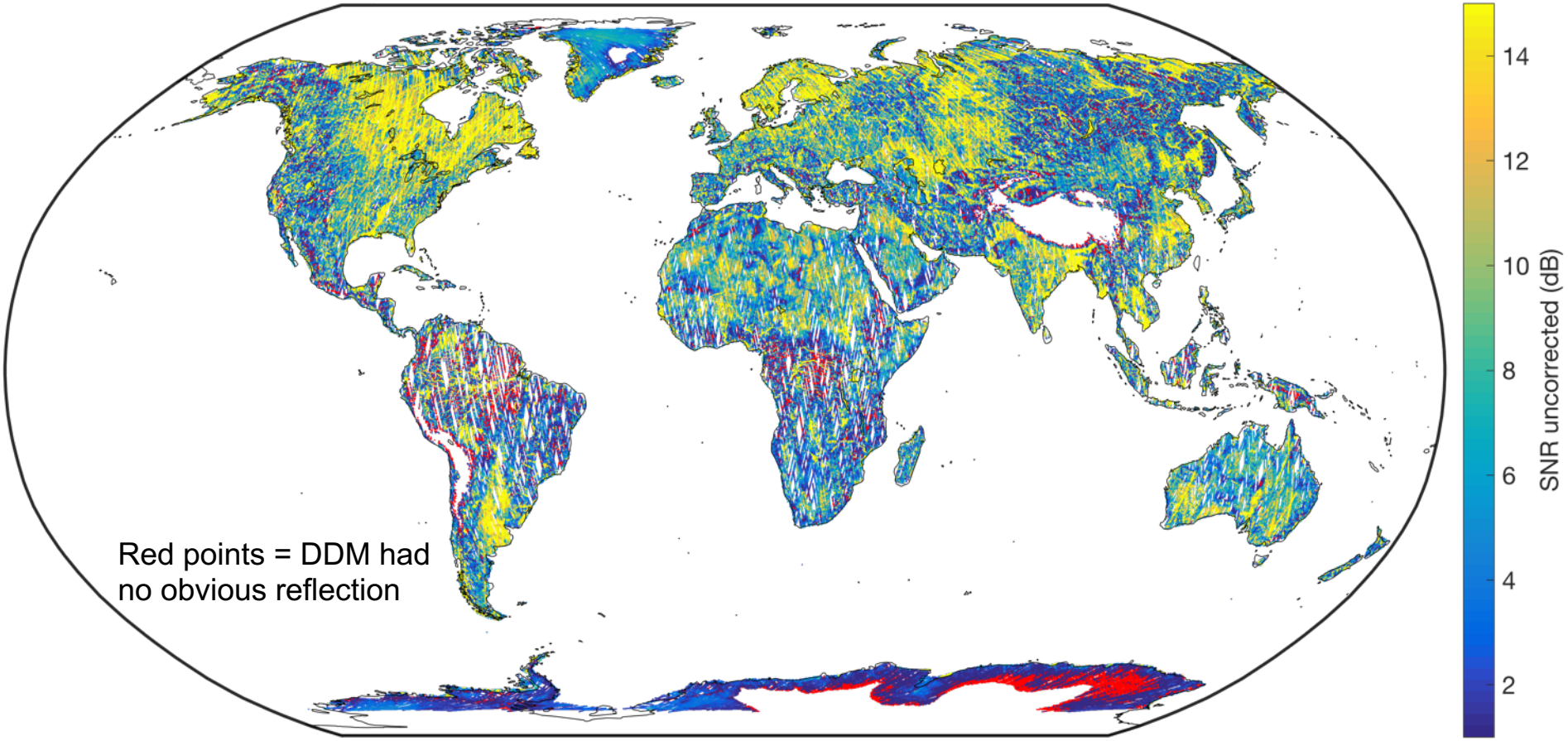
- Very rough: Incoherent scattering
- Large spatial footprint: 25 km

What do data look like recorded over land?



- If smooth, coherent scattering
- Variable footprint: 0.5 – 25 km

June 2015 – April 2016



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Rainfed Crops

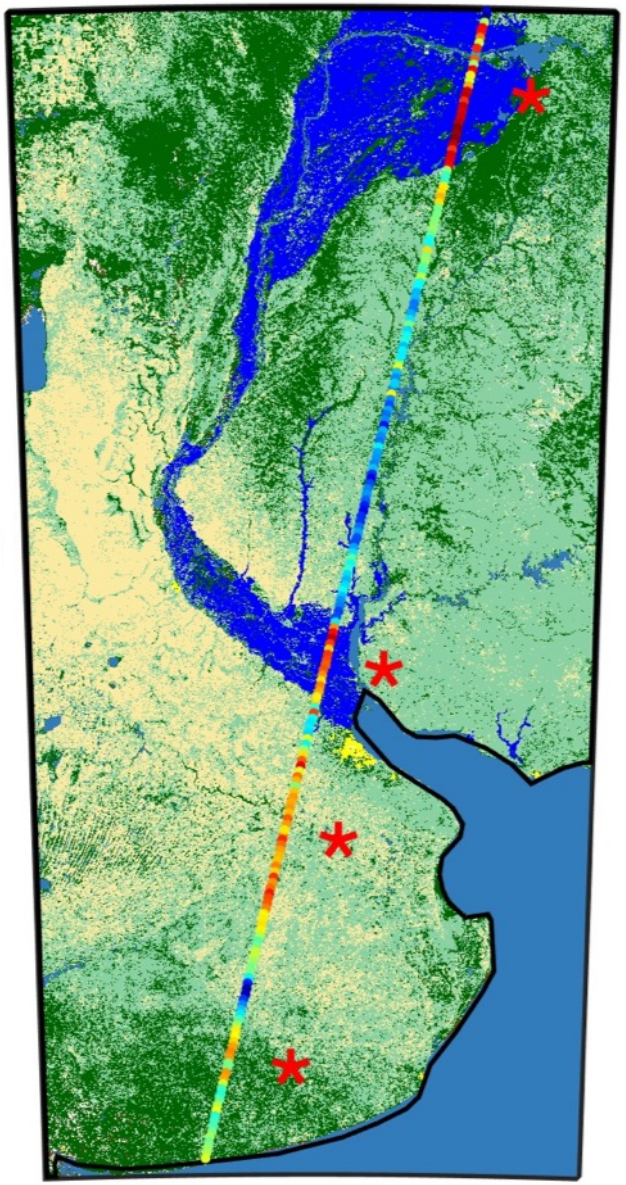
Mosaic Cropland/Natural Ve

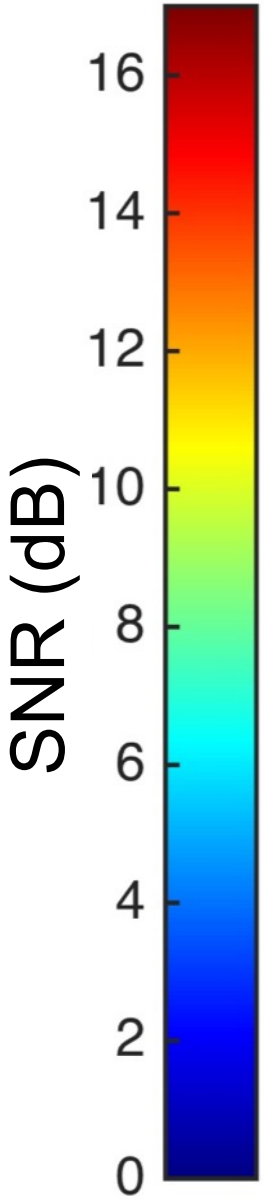
Forest or Shrubland

Regularly Flooded Soil

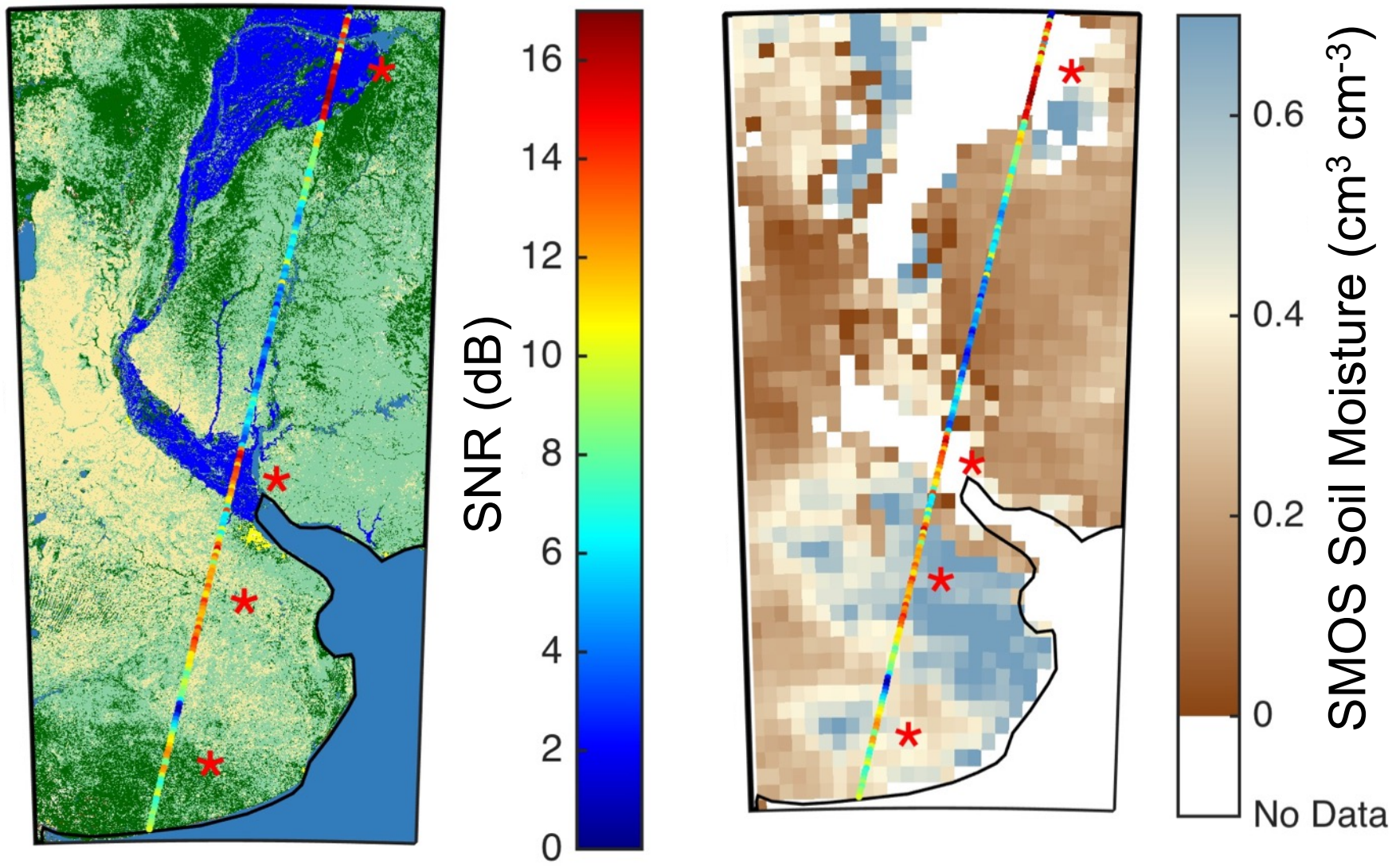
Urban

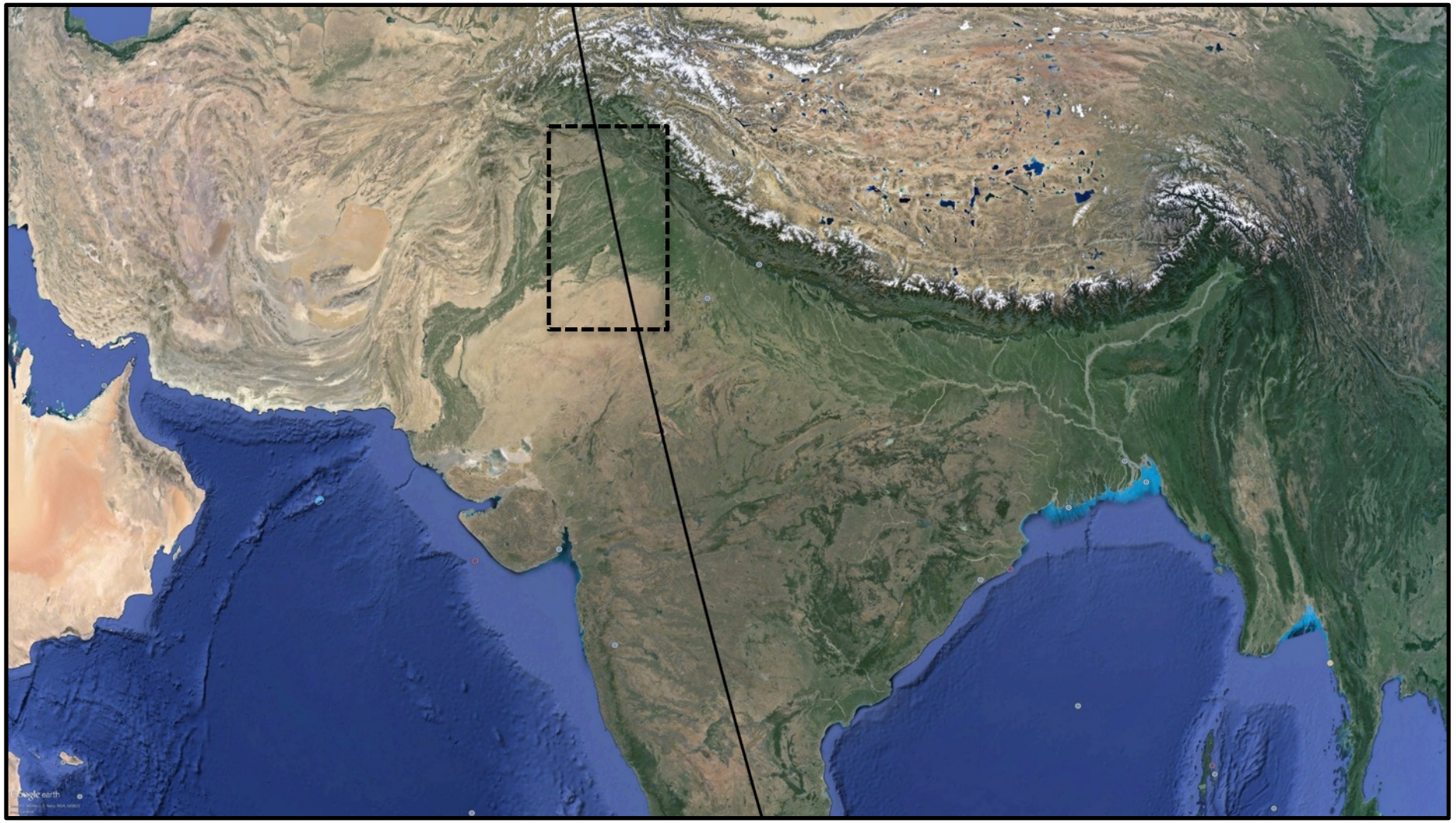
Water





* = Regions of High SNR (dB)


SNR (dB)
16
14
12
10
8
6
4
2
0
SMOS Soil Moisture (cm3 cm-3)
0.6
0.4
0.2
0
No Data

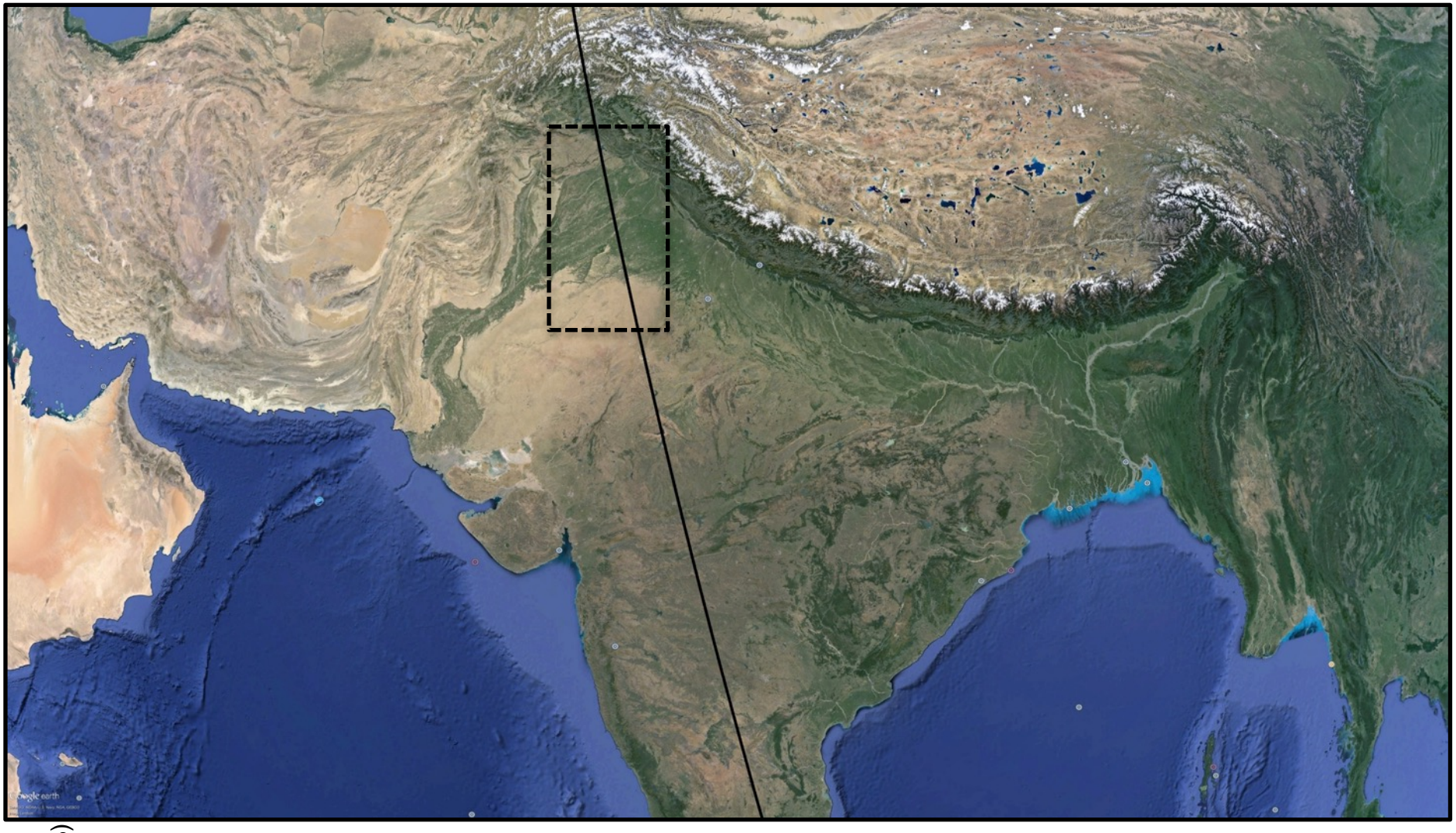


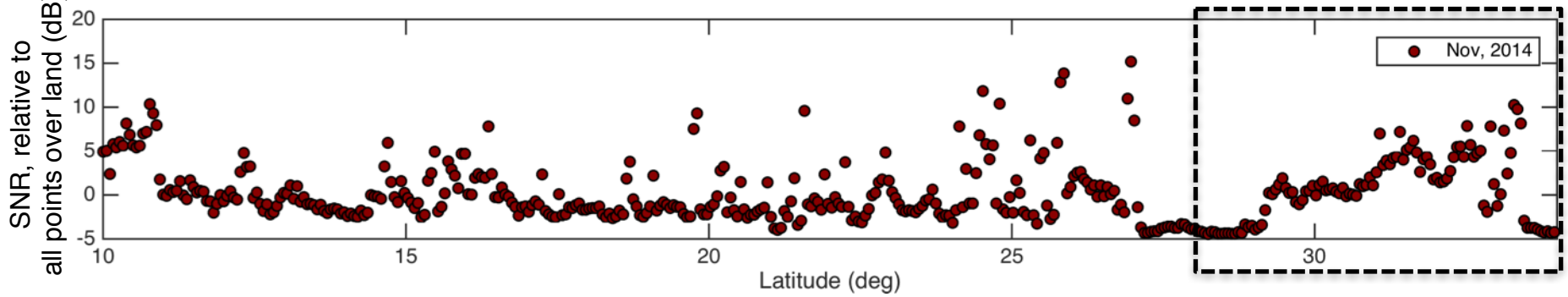
Punjab region of India and Pakistan

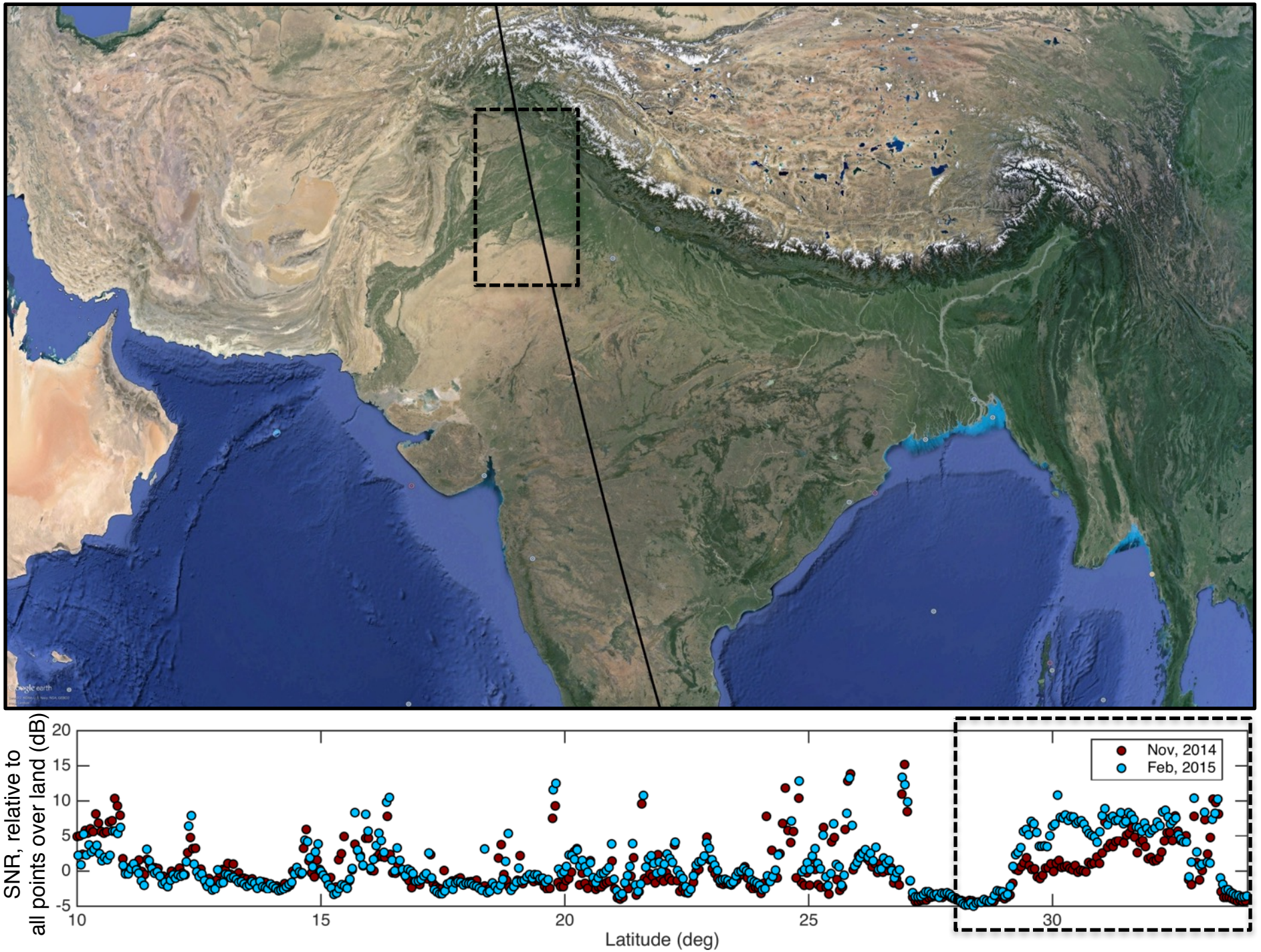
Agricultural region

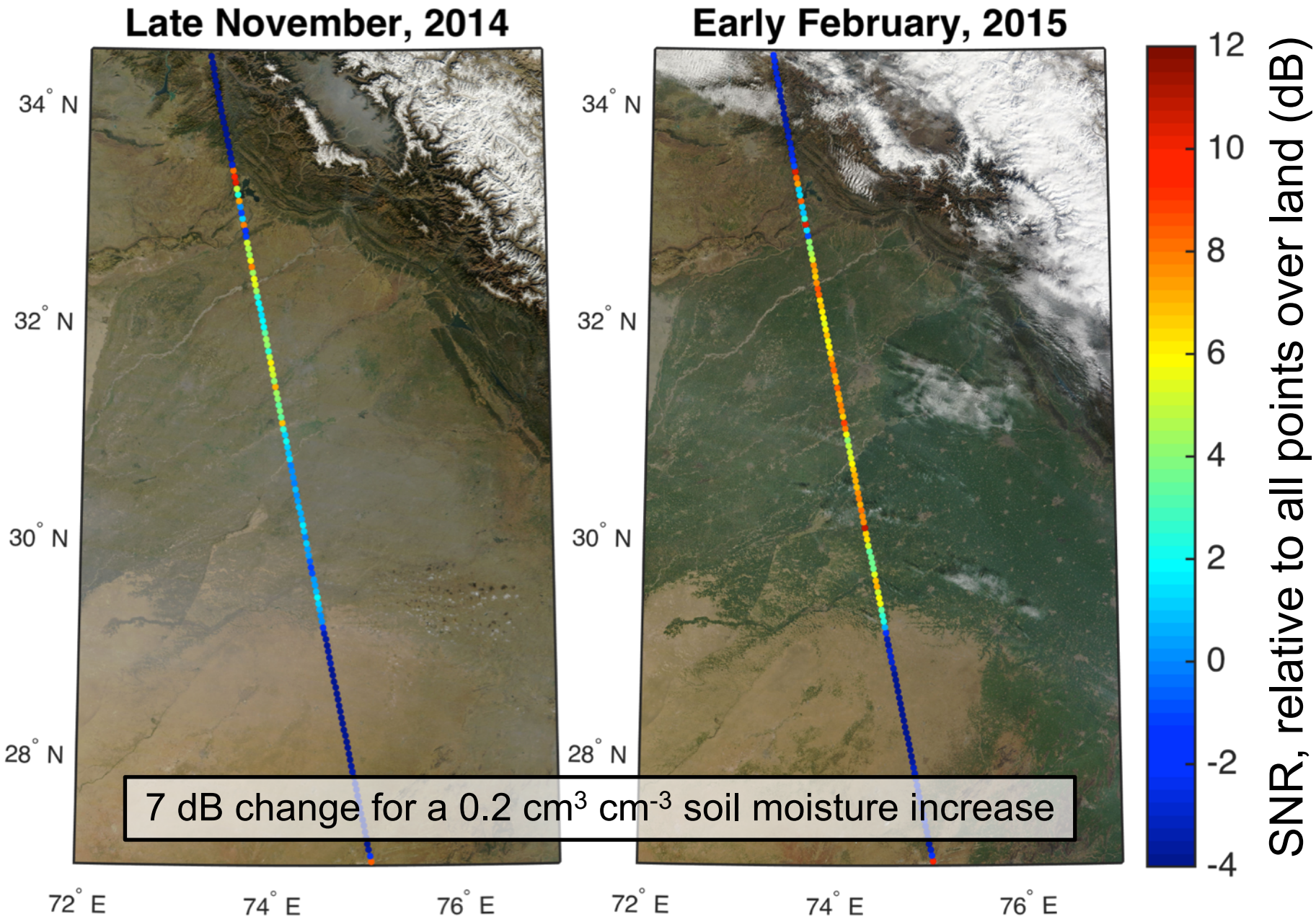
Heavily irrigated during growing season

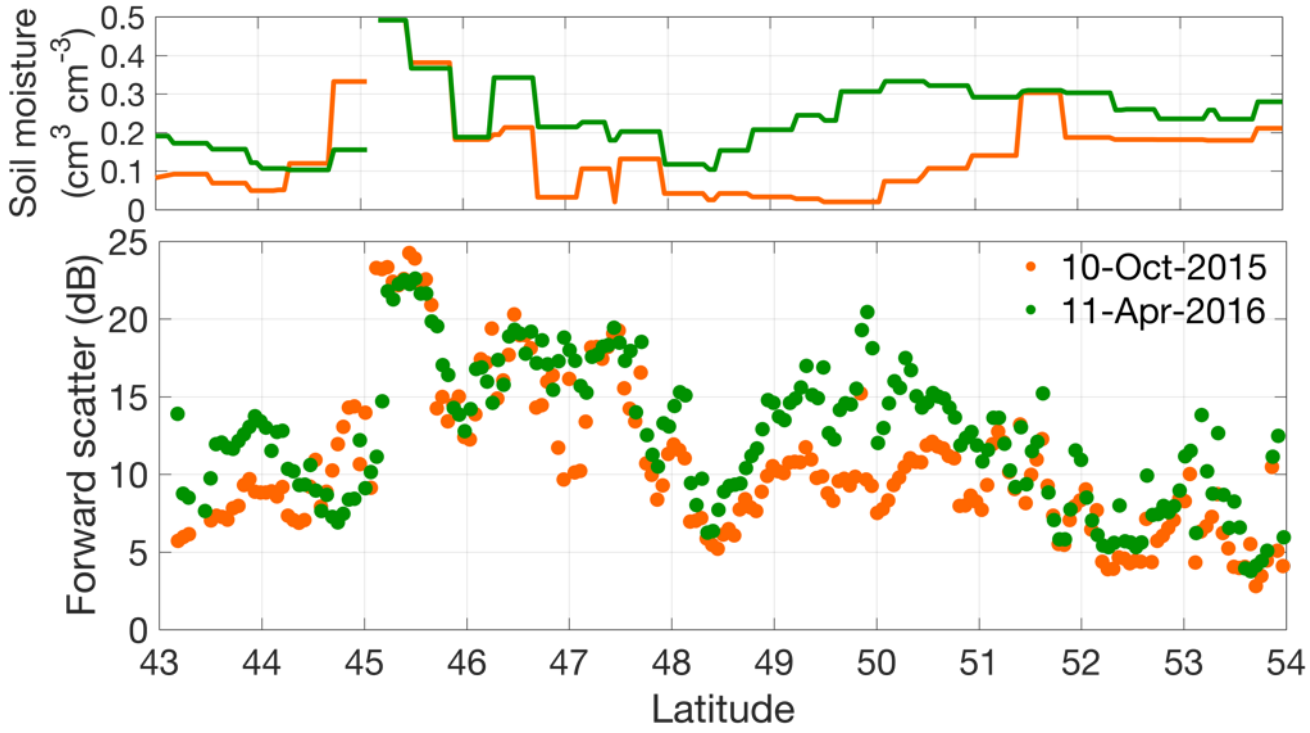
Crops sown in November, harvested in April



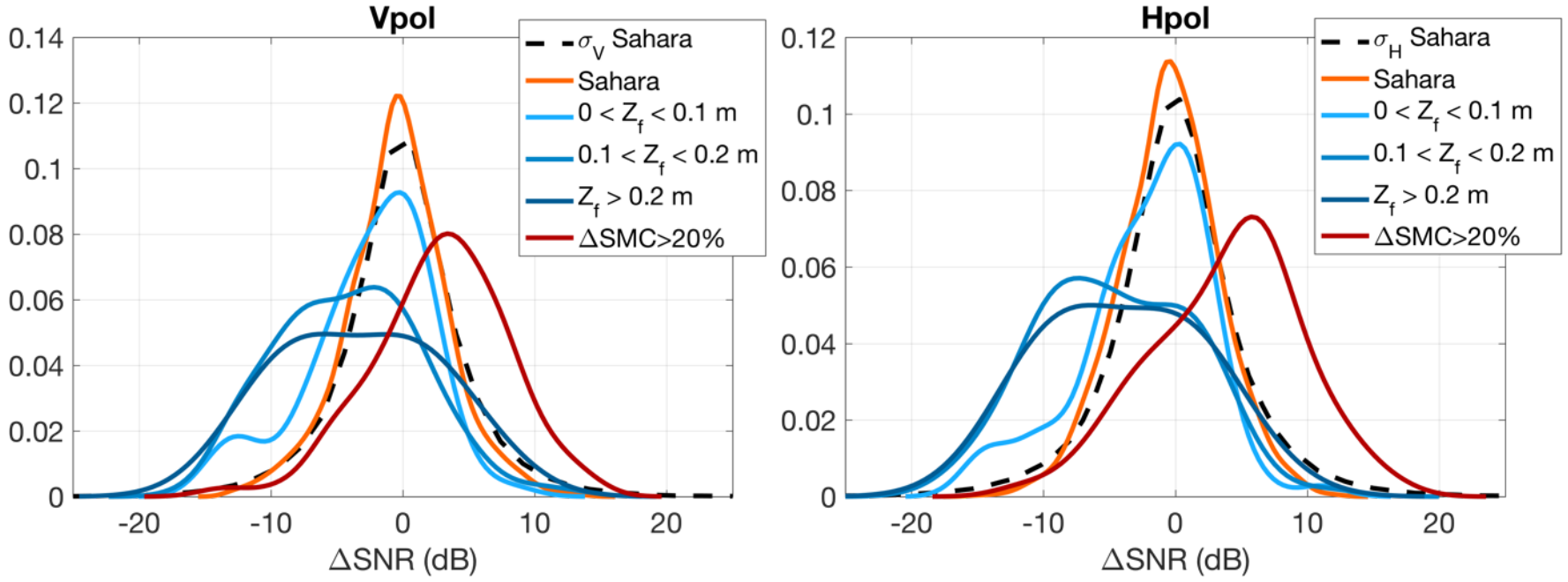

SNR, relative to all points over land (dB)
20
15
10
5
0
-5
10
15
20
25
30
Latitude (deg)
Nov, 2014


SNR, relative to all points over land (dB)
20
15
10
5
0
-5
10
15
20
25
30
Latitude (deg)
Nov, 2014
Feb, 2015


Late November, 2014
Early February, 2015
34° N
32° N
30° N
28° N
72° E
74° E
76° E
7 dB change for a 0.2 cm3 cm-3 soil moisture increase
12
10
8
6
4
2
0
-2
-4
SNR, relative to all points over land (dB)


Soil moisture
(cm3 cm-3)
0.5
0.4
0.3
0.2
0.1
0
Forward scatter (dB)
25
20
15
10
5
0
10-Oct-2015
11-Apr-2016
43
44
45
46
47
48
49
50
51
52
53
54
Latitude

Do this just for soil moisture



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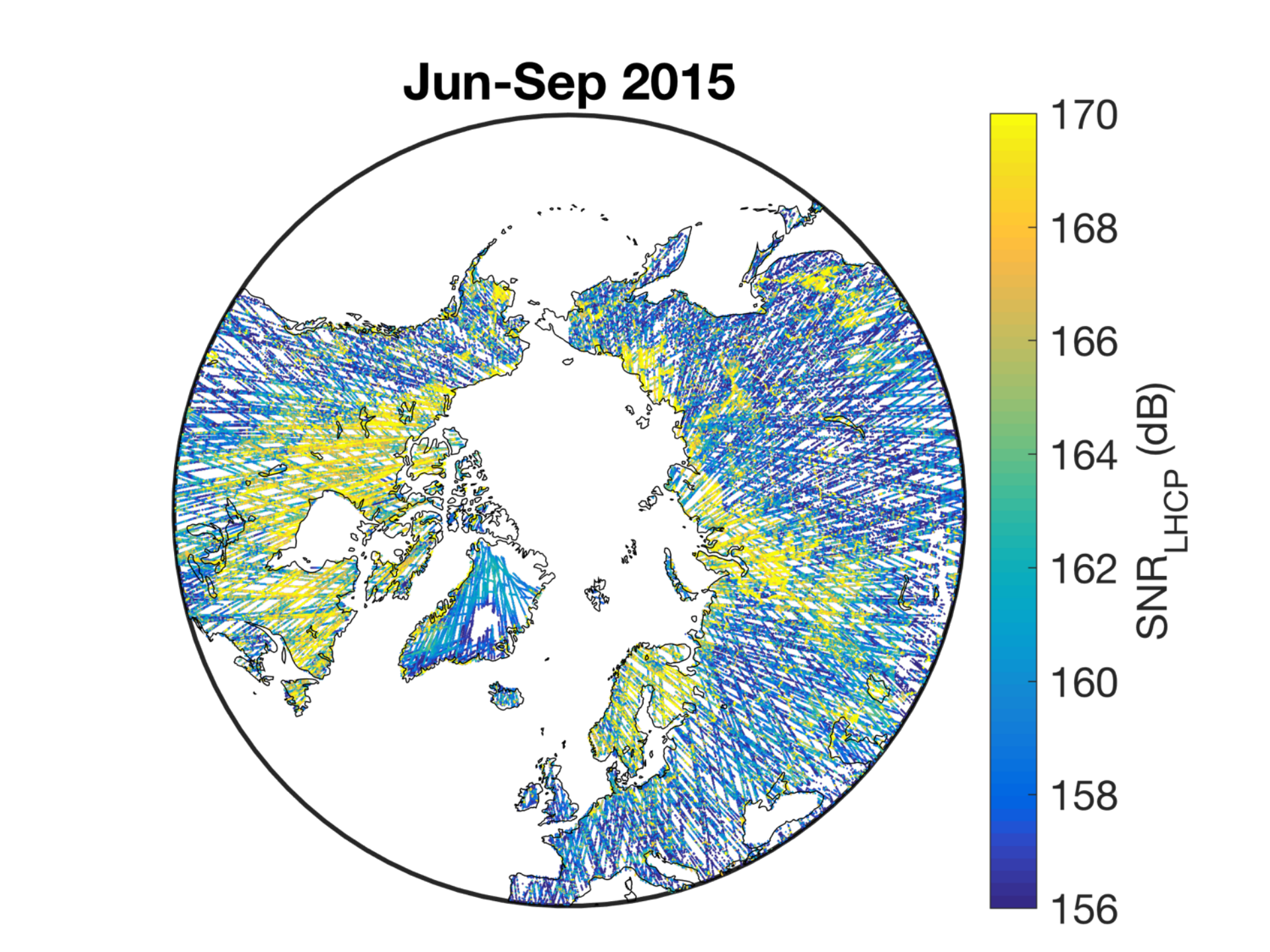
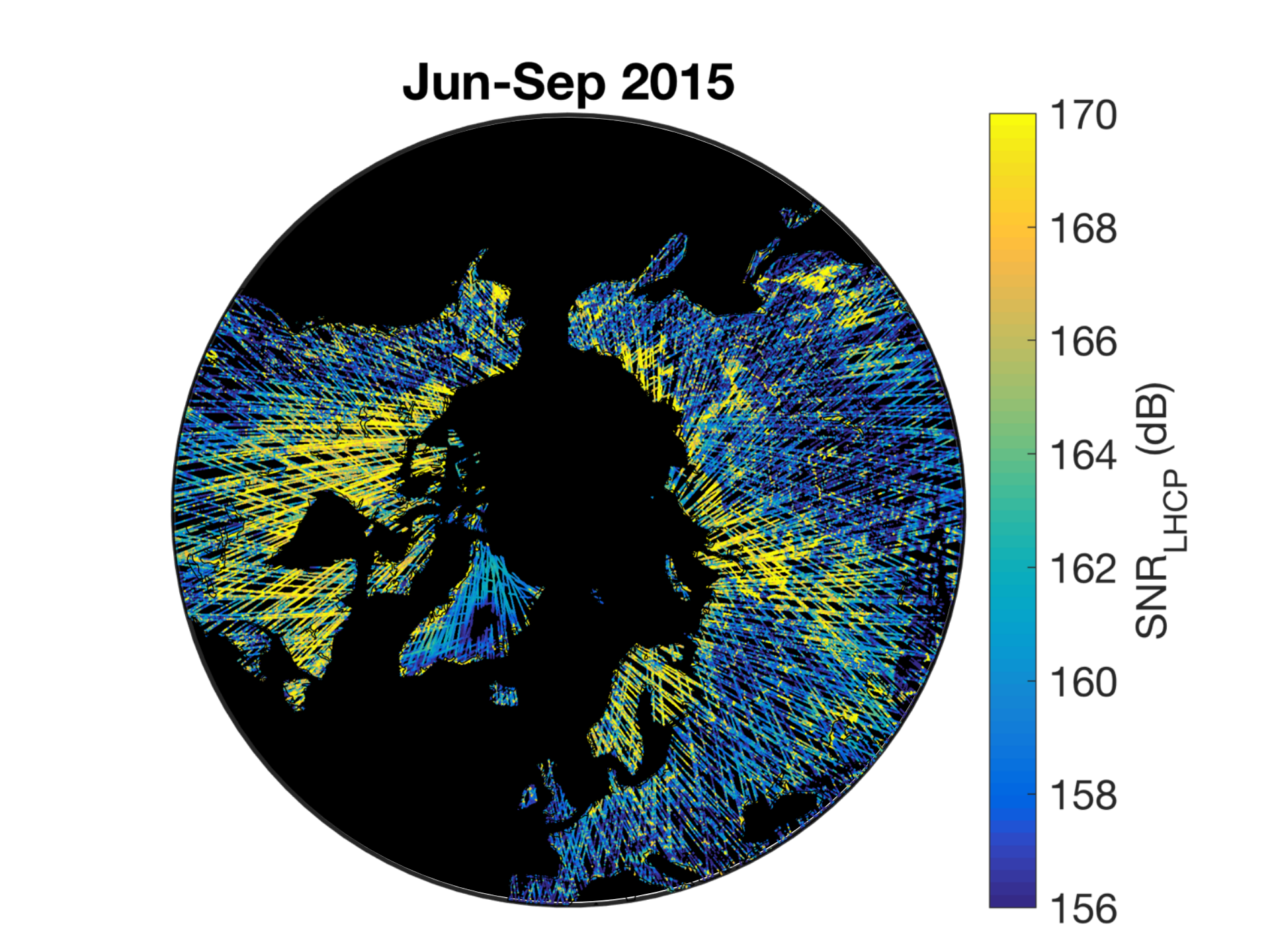
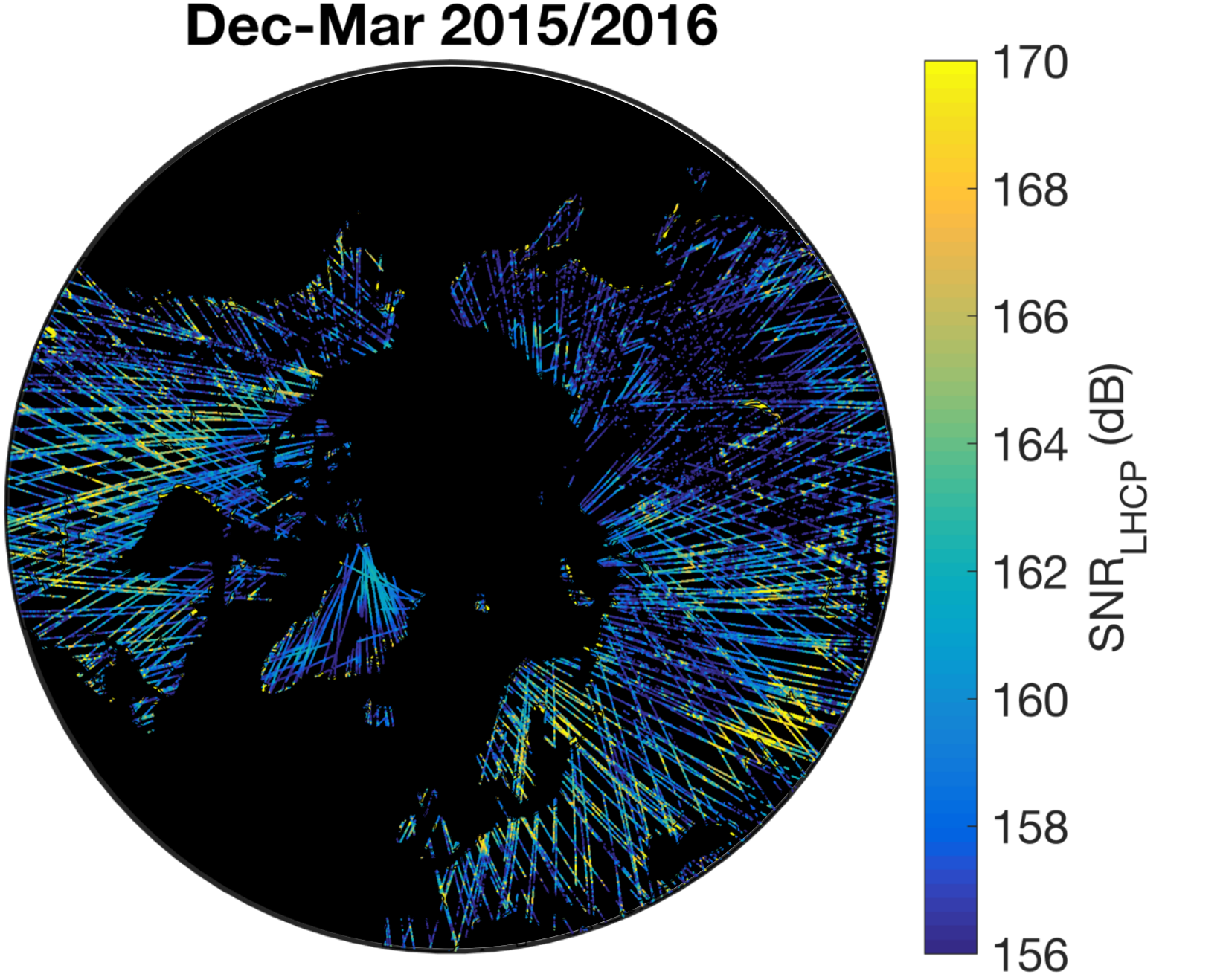
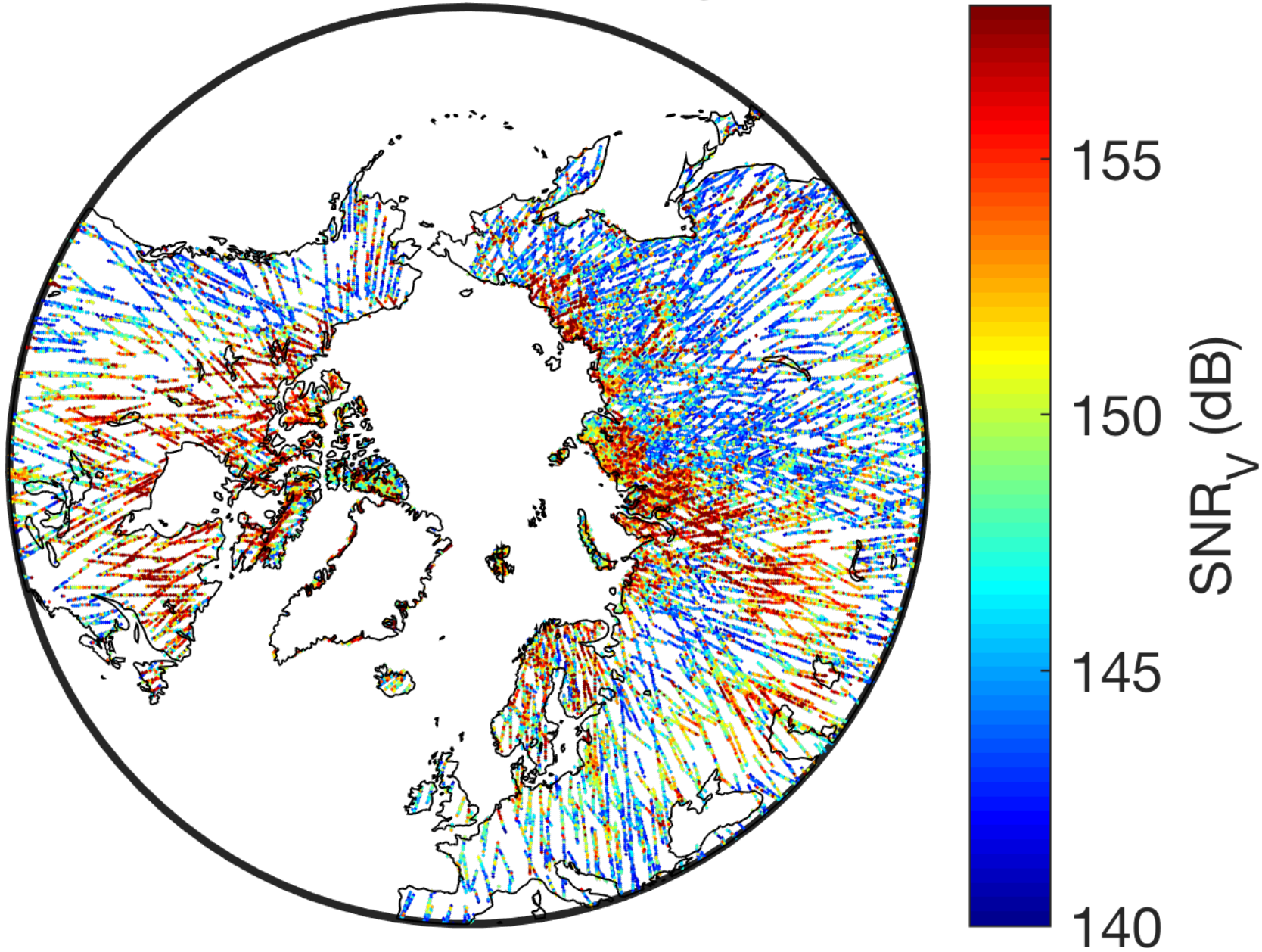

Jun-Sep 2015
170
168
166
164
162
160
158
156
SNR_LHCP (dB)

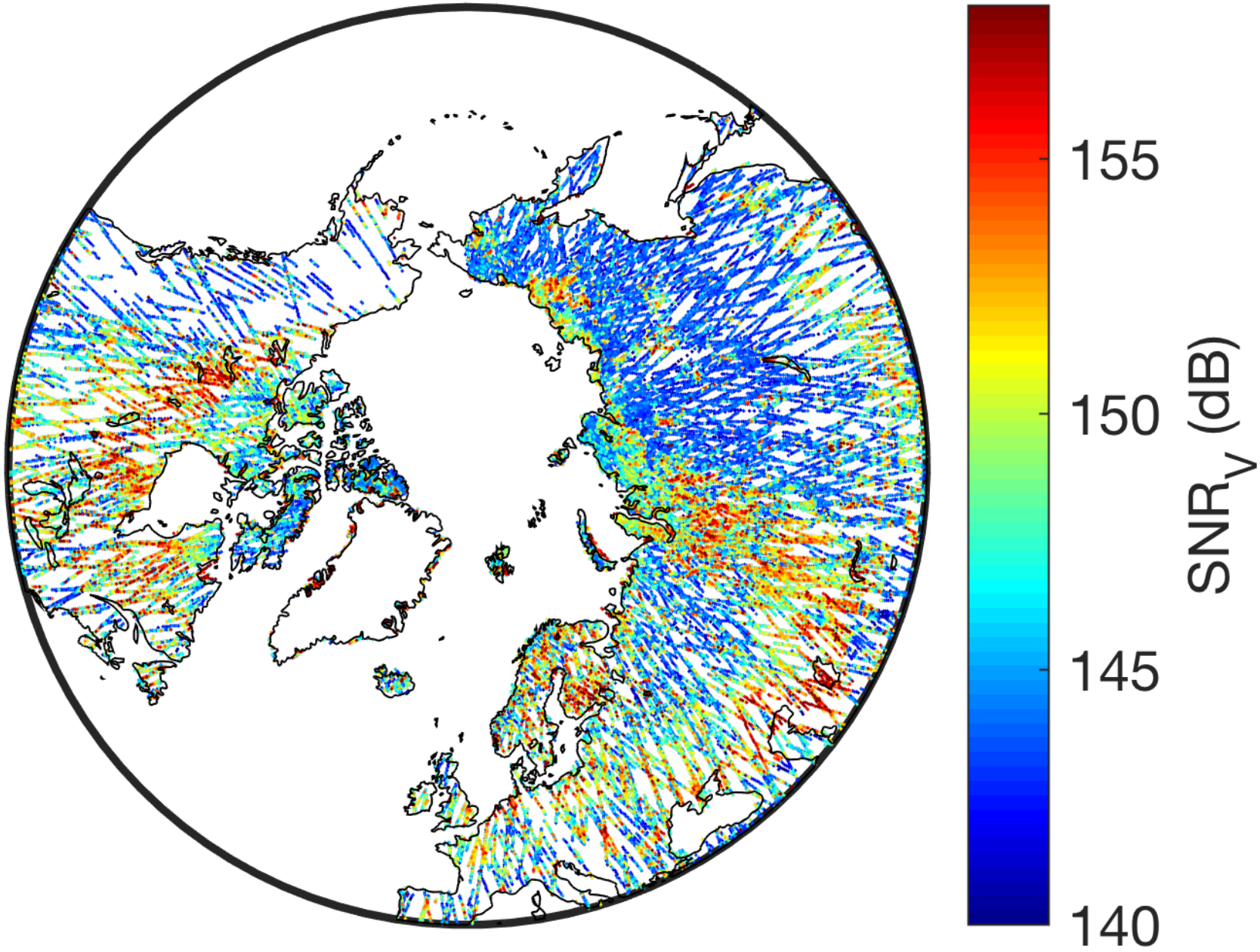

Jun-Sep 2015
170
168
166
164
162
160
158
156
SNR LHCP (dB)

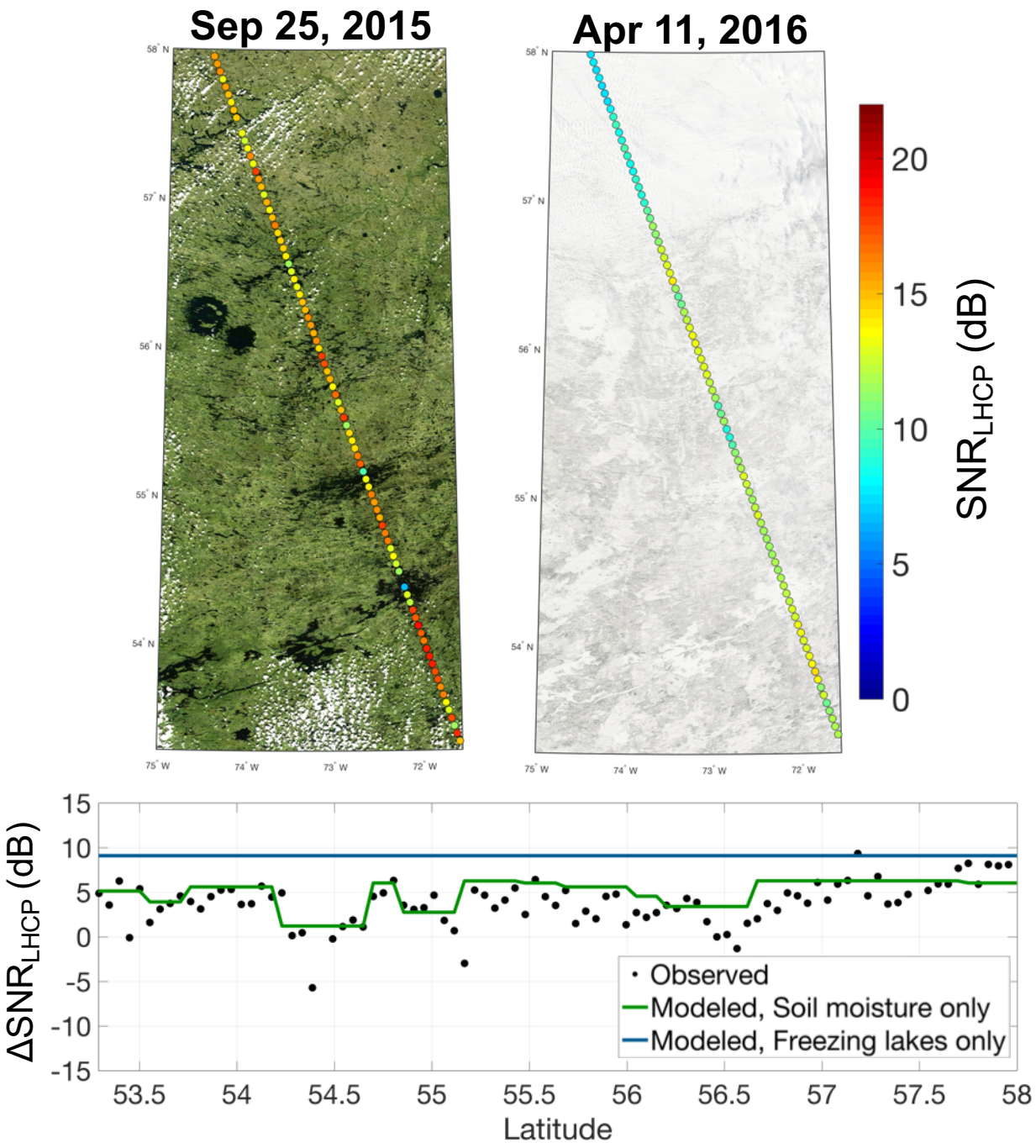

Dec-Mar 2015/2016
170
168
166
164
162
160
158
156
SNR LHCP (dB)

Summer: Jun, Jul, Aug 2016

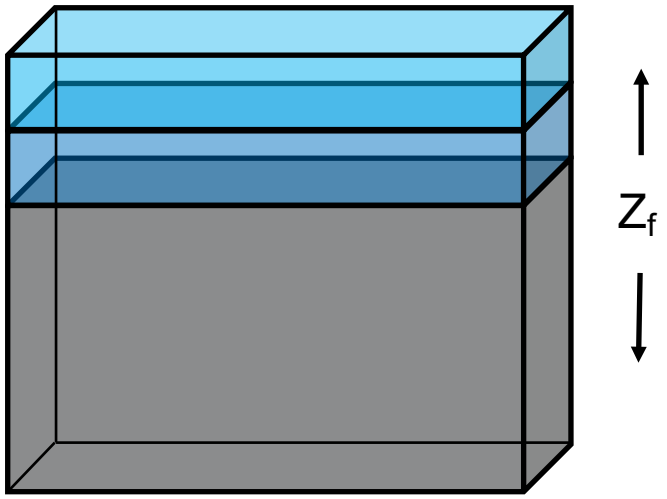


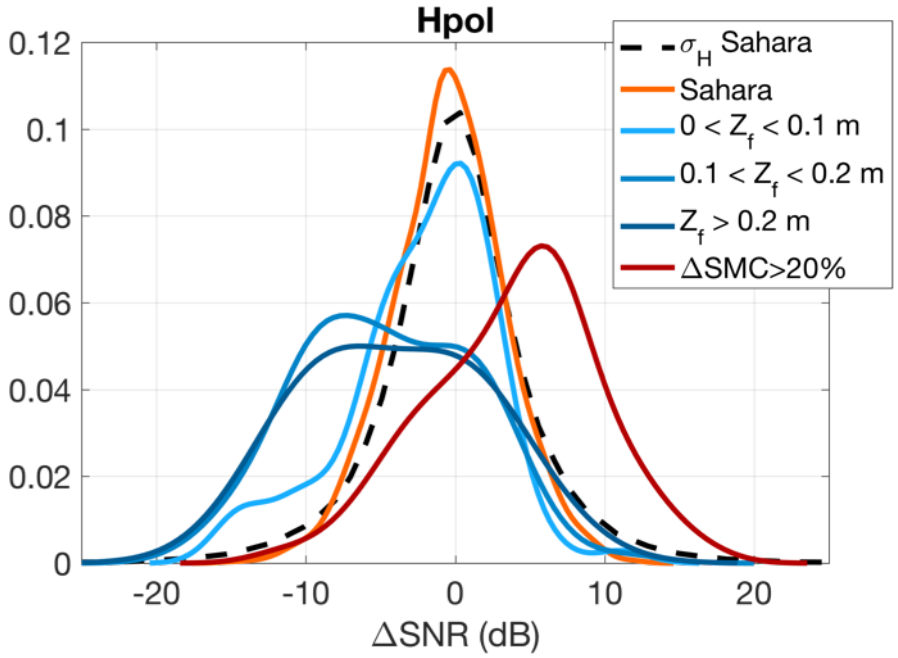
Winter: Dec, Jan, Feb 2015/2016



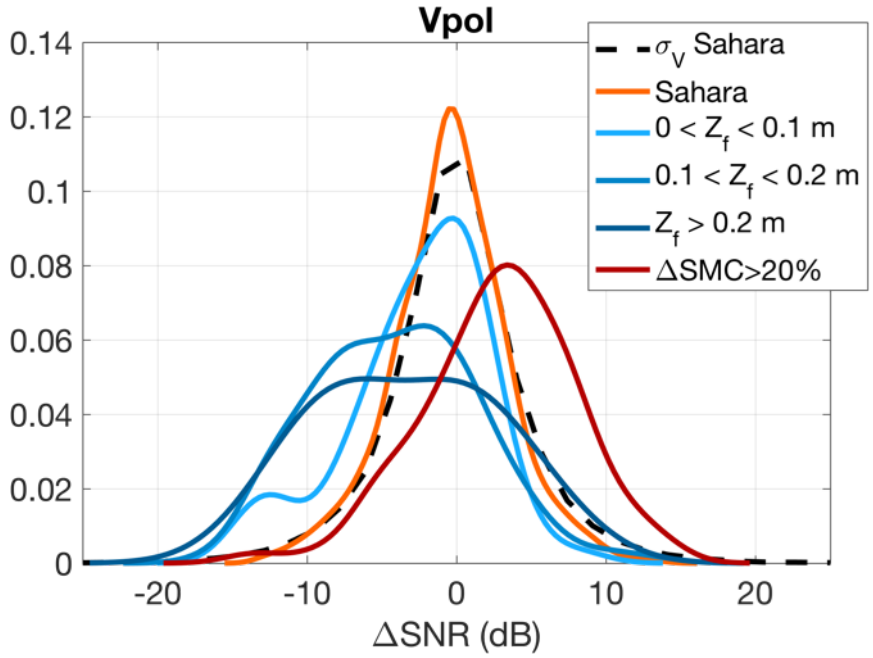

Sep 25, 2015
Apr 11, 2016
58° N
57° N
56° N
55° N
54° N
75° W
74° W
73° W
72° W
20
15
10
5
0
SNR$_{LHCP}$ (dB)
15
10
5
0
-5
-10
-15
ΔSNR$_{LHCP}$ (dB)
53.5
54
54.5
55
55.5
56
56.5
57
57.5
58
Latitude
Observed
Modeled, Soil moisture only
Modeled, Freezing lakes only

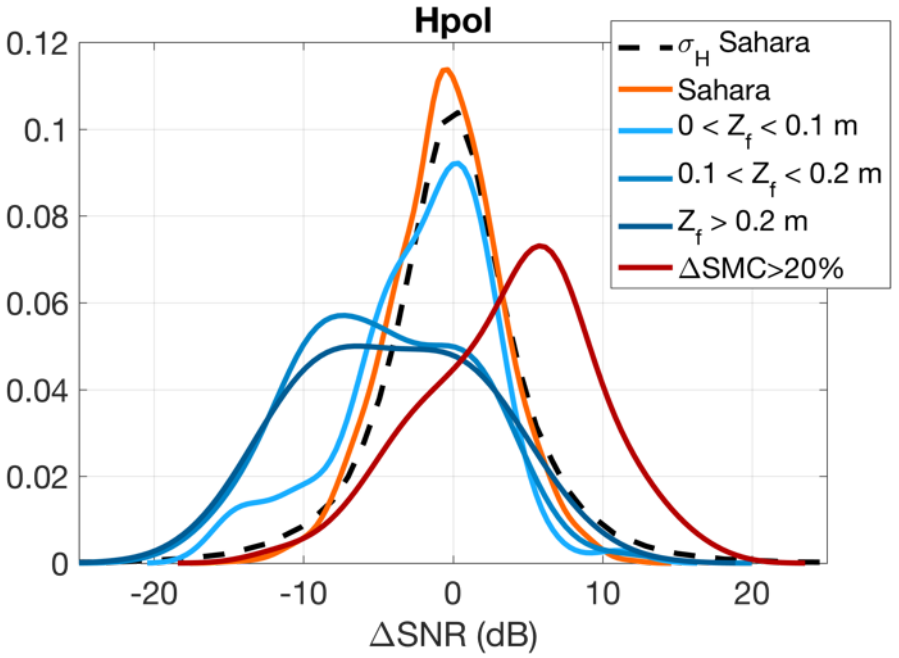
Changes of collocated reflections over time



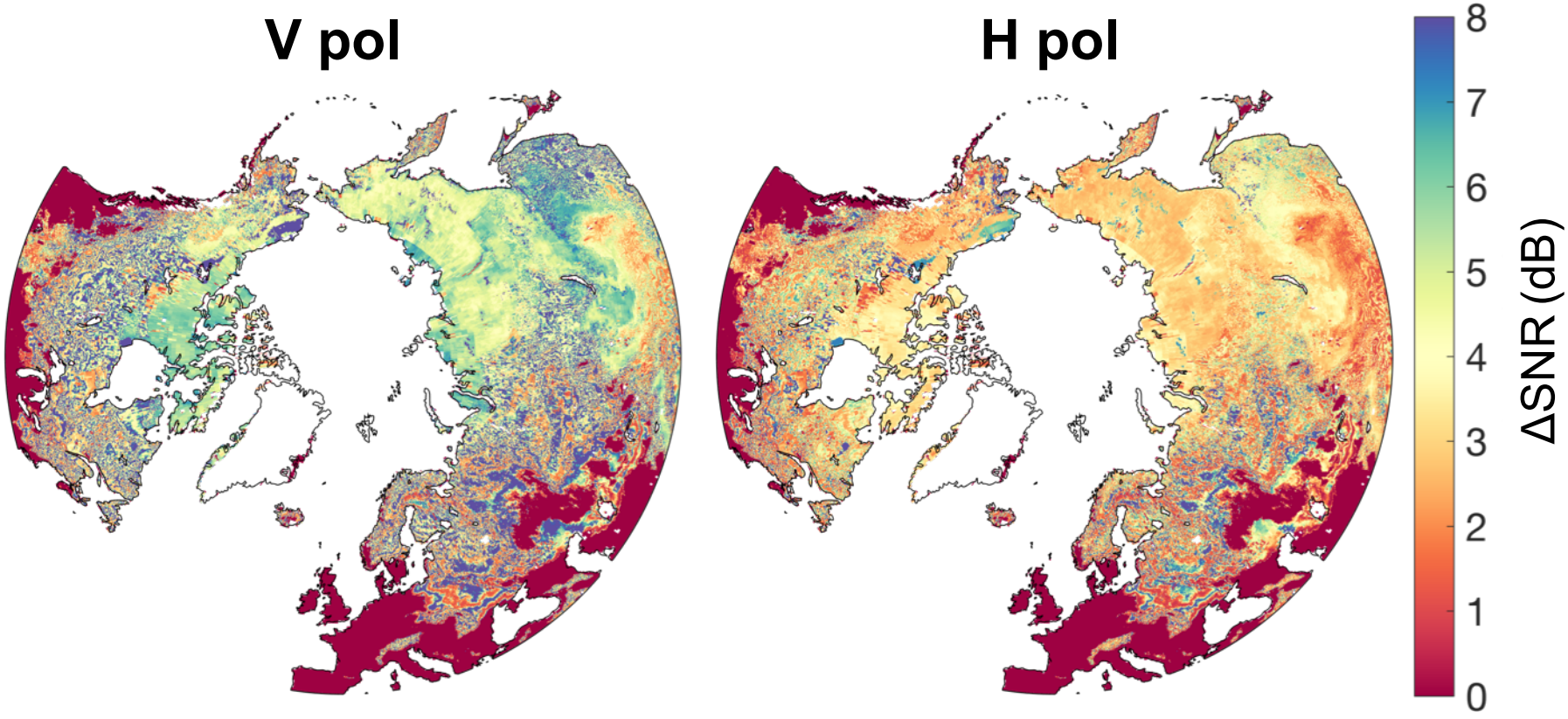


Changes of collocated reflections over time





Modeled changes due to F/T



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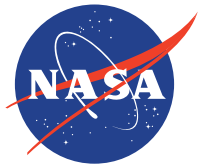

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